On-orbit Quantification of Combined Uncertainty for Infrared CLARREO

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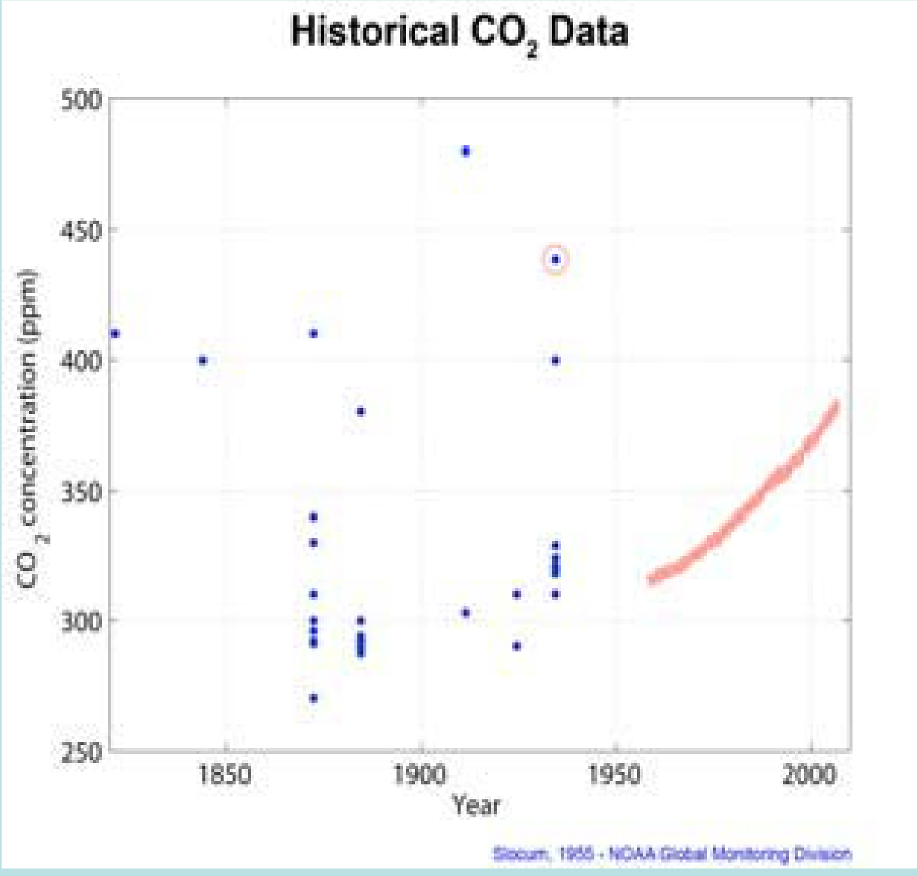
Introduction

The CLimate Absolute Radiance and Refractivity Observatory (CLARREO) mission is a new remote sensing mission begun by the National Aeronautics and Space Administration (NASA). The infrared component of the CLARREO mission utilizes advances in radiometric standards pioneered by the precision metrology community. These standards provide an on-orbit link to the International System of Units (SI), deemed necessary to accurately capture small secular trends associated with anthropogenic climate forcing. This poster investigates the use of these traceable, on-orbit standards (blackbodies) for the quantification of type B uncertainties arising in the spectral infrared sensor over the lifetime of the mission.



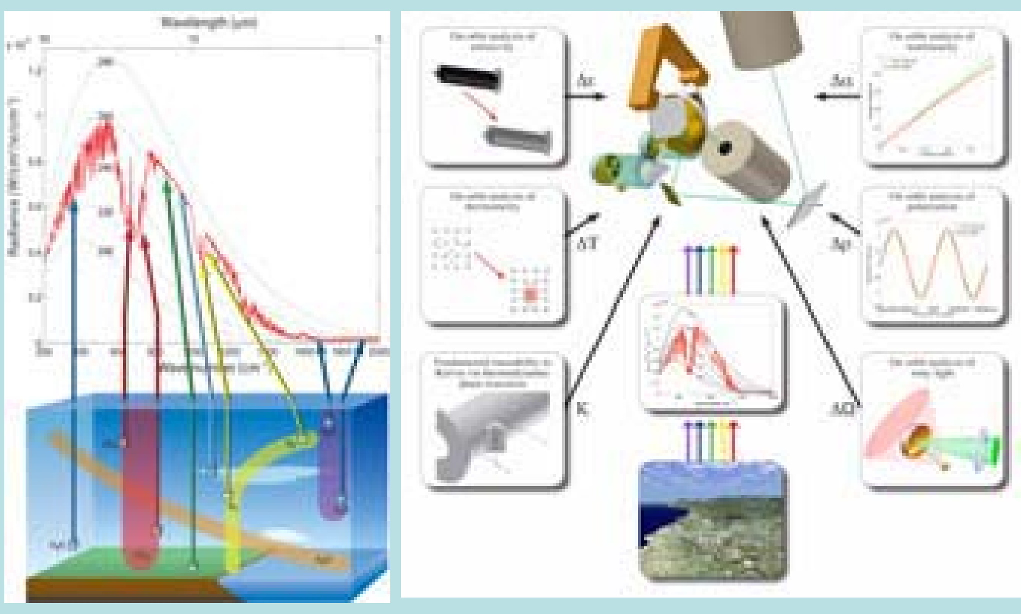
The utility of reproducible standards for climate: the blue points in this figure represent a collection of atmospheric carbon dioxide (CO2) measurements culled from a wide variety of investigators in a review paper by Slocum (1955). The point circled in red was deemed by Slocum to be the most reliable as it was an average of 50,000 measurements. Slocum concluded that atmospheric carbon dioxide was most likely decreasing. Charles Keeling introduced reproducible calibration standards, calibrated by both manometric and infrared techniques, and thereby initiated the single most important measurement time series for understanding contemporary climate change. The success of Keeling's efforts informs the climate community's appeal to SI traceability to further understand current climate trends and to predict climate more accurately in the future.

An SI Traceable Climate Index

Profiles of microwave refractivity obtained by radio occultation using the Global Navigation Satellite System (GNSS) provide a benchmark of climate that is on-orbit traceable to the international definition of the second.

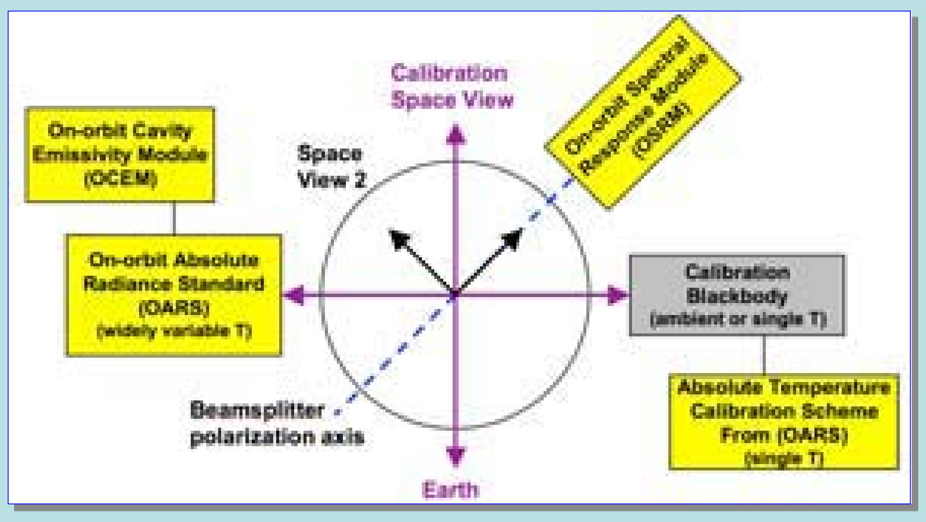
The SI traceability of the on-orbit GNNS timing measurement is obtained through double-differencing: a reference phase is measured during an occultation from an independent GNSS satellite, and both the reference and occulting satellites are observed with an atomic clock on the ground.

Spectral IR Radiances for Climate

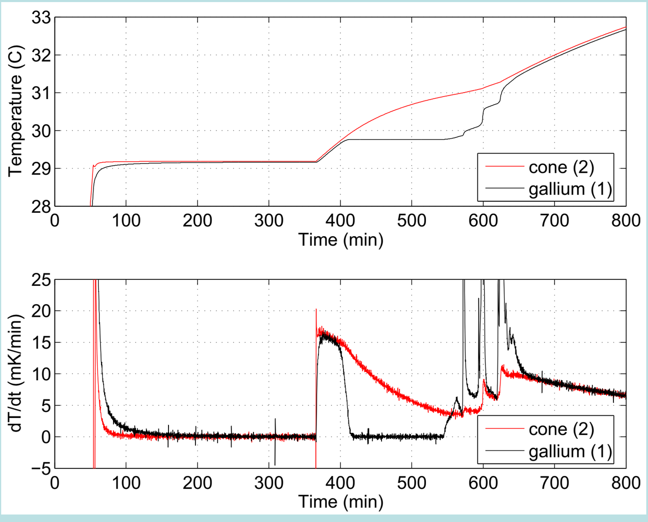


The infrared radiation exchanged within the Earth's atmosphere, oceans, land surface, and cryosphere, and emitted back to space to balance the solar radiation absorbed by the system, controls the long-term climate of the Earth. For this reason, long-term, high accuracy, comprehensive observations of infrared radiation from space are essential to the success of climate research and the ensuing delivery of timely and relevant decision support.

Checking Uncertainty On-Orbit

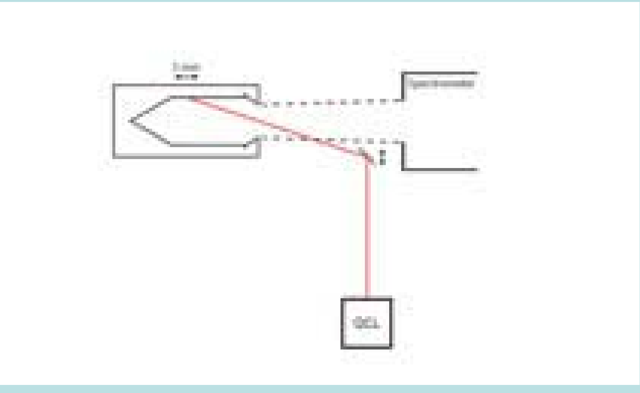


These observations must possess the capability to provide on-orbit demonstration that the required level of measurement accuracy is met to a critical adjudicator. Practically, this capability is obtained via a nadir-observing infrared spectrometer in Earth orbit measuring absolute spectrally resolved radiance with high accuracy (0.1 K/ 3-sigma brightness temperature).



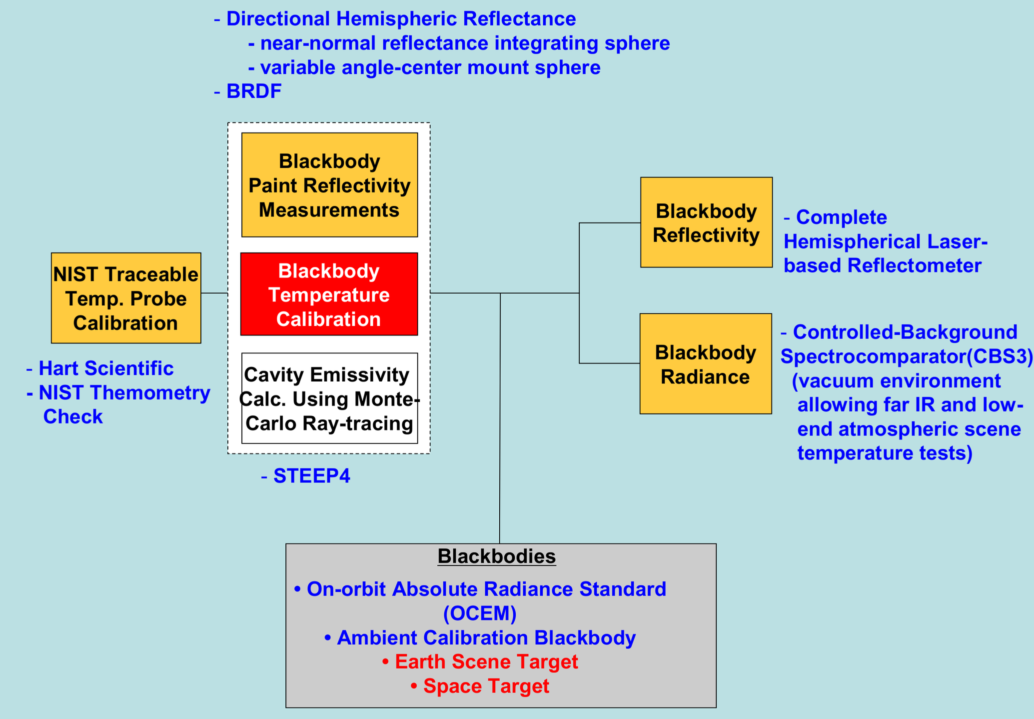
The on-orbit absolute temperature calibration for the this self-calibrating blackbody uses melt signatures from three (or more) different phase change materials that provide absolute calibration for the blackbody thermistor sensors covering a wide, continuous range of atmospheric temperatures.

Quantum Cascade Lasers (QCLs) offer compact, efficient, monochromatic mid-infrared sources to realize on-orbit reflectometry to directly observe blackbody surface properties. Increases in the surface reflectivity of the blackbody cavity are detected as increases in this reflected power over time.

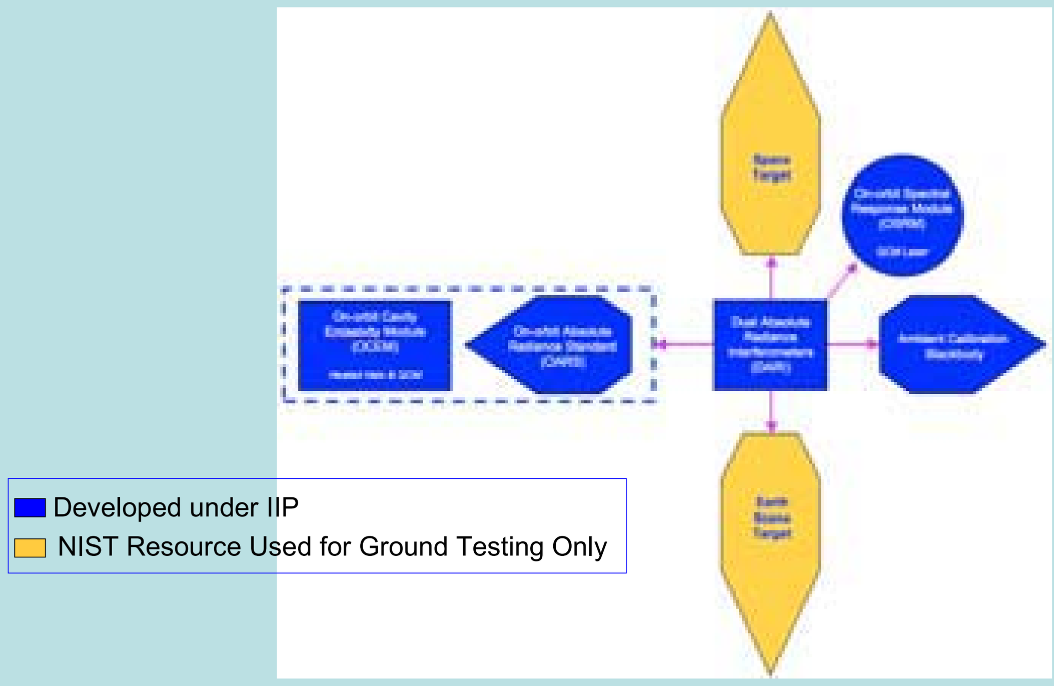


Traceability to NMIs

Meeting the CLARREO traceability objective requires the development of satellite-borne infrared standards that are analogous to the measurement standards maintained by National Measurements Institutes (NMIs). The basis of modern measurement standards is the Système Internationale (SI). By deploying infrared remote sensors with measurement scales directly traceable to the SI, this observational goal may be met.



Since blackbodies provide the foundation for traceable measurements in the thermal infrared, the CLARREO blackbodies should be thoroughly characterized to put end-to-end constraints on uncertainty. This characterization includes traceability NMI thermodynamic and optical scales.



NMIs can provide artifacts for system-level calibration as well as piecewise calibration to increase confidence in the estimates of system-level sensor performance.

Conclusions

Experimental prototypes have been for on-orbit temperature calibration and emissivity monitoring have been demonstrated. Direct measurement of blackbody performance on-orbit is an improvement over previous methods for remote sensing calibration which have relied on pre-launch data or to intercomparisons campaigns that only test system-level uncertainty. These blackbody diagnostics underpin the strategy for constraining type B uncertainties for the infrared component of the CLARREO mission. The resulting CLARREO measurements, with high-accuracy calibration, validated on-orbit, facilitate meeting the societal objective of improved long-term climate forecasts.